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Biomass energy in Bangladesh: Current status and prospects

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ABSTRACT

Bangladesh has been experiencing several problems over the past few decades. These include over population, energy crisis and global warming, etc. Adequate amount of power generation in a sustainable way is an important issue for rapidly increasing population and economic development. Renewable energy can play an effective role to meet energy demand. Since it is an agrarian country, biomass is one of the potential renewable energy sources in Bangladesh. Agricultural crop residues, animal manure and municipal solid waste are the major sources of biomass energy in the country. This paper presents the scope, potential and technologies related to the use of biomass resources. The study also discusses the biomass projects undertaken by the government and non-government organizations, plans and strategies to promote biomass technologies in Bangladesh.

Contents

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1. Introduction

Bangladesh is one of the least developed and densely populated nations in the world. According to the reports of Bangladesh Bureau of Statistics (BBS)—2005, around 40% and 25.10% of the total population live below the upper and lower poverty lines, respectively. The rate of poverty in the rural areas is higher than the urban areas. In the rural areas, about 43.80% of people live below the upper poverty level, while 28.60% in the urban area [1]. Access to electricity is one of the essential preconditions for reduction of poverty, improvement of living standard, establishment of environmental sustainability and overall agricultural and socio-economic developments in the rural areas.

Currently, around 49% of the people in Bangladesh are connected to electricity grid. More than 70% of the people live in the rural areas, where only about 25% have access to electricity. As a part of the programs for developing living standard of rural people, the government has planned to electrify the entire country by the year 2020 [2]. According to the government strategy, the goal of this plan will be achieved through short, medium and long term programs for increasing electricity generation by using natural gas, coal, liquid fuel, nuclear energy and also renewable energy sources.

At present, production of natural gas in Bangladesh is about 1100 million cubic feet/per day, while about 3 million tons of petroleum products are imported every year. The commercial energy sources provide about 27% of the total energy consumption in the country, which are mainly used in industrial and urban areas. Industrial areas are mostly located in cities and the people in the cities are the consumers of commercial energy. Whereas, the majority of the rural people of the country have no commercial energy supply [3–6]. The percentage of population having access to gas is about 6%, primarily in urban areas. However, in recent years, due to the lack of exploration of new gas fields and depletion of present gas reserves, supply of natural gas has been in jeopardy [7]. Such a situation has restricted further installation of power generation plants using natural gas. Due to this concern, the government has planned to find alternative sources of fuel, other than gas and oil. According to the plan, liquid energy and coal will support significant portions of electricity generation. However, renewable energy is one of the promising fields that can be contributed to the diversification plan. In addition, due to the financial constraints, inaccessibility and low consumer density in many rural areas, the electrification through grid expansion may not be pragmatic. To reach the goal, renewable energy sources can play an imperative role for off-grid electrification.

Naturally, biomass is a potential source of energy in Bangladesh. The rural economy is plagued by slow growth rate, unemployment problem, deficient infrastructure and abject poverty. Currently, Bangladesh is the seventh most crowded countries in the world and biomass provides 73% of the total energy [8]. Biomass resources (such as wood, cow dung and agricultural wastes) available in rural areas are utilized as cooking fuel. In the rural areas, only 5% people use kerosene as fuel [9]. For the purpose of lighting the houses, most of the people in the village use kerosene based lamps.

Nowadays, biomass is being utilized to generate renewable energy in many countries of the world. Biomass covers about 50 exajoule per year of total primary energy demand of the world [10]. The generation of energy from biomass offers a number of advantages. The cost of biomass residues is low and the energy conversion efficiency is high comparing with other fossil fuel based generation techniques. Thus it reduces the ultimate cost of electricity. Besides energy, the technology also provides organic fertilizer, increases crop production, promotes a clean and green environment [11].

The paper is organized as follows. Section 2 discusses the energy scenario of Bangladesh and geographical supports for biomass production. Sections 3 and 4 describe the biomass resources in the country and energy potential from biomass respectively. Sections 5 and 6 present the available biomass to energy conversion technologies and available biomass related technologies in Bangladesh. Finally, the plans and promotion strategies undertaken by different organizations are mentioned in Section 6.

2. The Bangladesh scenario

2.1. Energy status and demand

The current population of Bangladesh is about 160 million and the country has an area of 147,570 km^2 [12]. Per capita electricity generation is an assessment of physical quantity of life and it is low in Bangladesh. Currently, per capita electricity generation is about 292 kWh/year. The demand for electricity is in all sectors of the economy including agriculture, industry and service sectors. Domestic and industrial sectors consume about 43% and 44% of electrical energy respectively, i.e. a total of about 87% of power consumption occurs in these two sectors [13]. Actual demand of electricity could not meet in the last few years due to insufficiency in maximum generation capacity. Table 1 shows the year-wise installed capacity and maximum generation of power plants. The total installed capacity was 5262 MW in FY 2007–08, which has increased to 8525 MW in FY 2012–13 with an annual increase of 10.34%. However, the maximum generation was 4130 MW in FY 2007–08, which has increased to 6350 MW in FY 2012–13 with an annual increase of 8.96%. The annual rise in maximum generation (8.96%) is lower than that of the installed capacity (10.34%) between the FY 2007–08 and 2012–13. This is mainly due to the less generation capacity of older power plants and shortage of gas supply.

The installed capacity and maximum generation were 8525 MW and 6350 MW respectively in August 2012, which is the maximum generation in the history of Bangladesh. It is approximated that the average generation capacity is around 6000 MW, while the actual demand is more than 7500 MW. Therefore, load shedding has increased. Within the reach of the national grid, Bangladesh is

Table 1
Year-wise installed capacity and highest generation in Bangladesh [14].

Fiscal year	Installed capacity (MW)	Maximum generation (MW)
2007–08	5262	4130
2008–09	5809	4162
2009–10	5978	4606
2010–11	6658	4890
2011–12	8100	6066
2012–13 (up to March)	8525	6350

still facing under 600–1200 MW of load-shedding. The situation becomes worse than before during irrigation seasons, when gap between energy demand and supply reaches up to 1500 MW. According to the Government Power Sector Master Plan—2010, the estimated electricity demand will be 19,000 MW in 2021 and 34,000 MW in 2030 [15]. Fig. 1 shows the growth rate of energy demand, generation and load shedding in Bangladesh. From the information during 2007–11, it is observed that the electricity demand was increased at the rate of 5.43%, while the generation of electricity was increased at the rate of 5.37% per year. The lower acceleration rate of electrical generation compared with the rise in demand increased the rate of load shedding, which has been rising at the rate of 6.72% per annum during this period [16].

Generation of electricity in Bangladesh is solely dependent on the availability of conventional sources like indigenous gas, furnace oil, diesel, hydro power and coal. Fig. 2 shows the installed capacity of power plants according to the fuel type in 2012. The highest 67.21% of total electricity generated using indigenous natural gas, which is followed by furnace oil (22.30%), diesel (5.52%), hydropower (2.58%) and coal (2.35%). Under the existing generation scenario, the contribution of renewable energy to the total power generation is very low.

Bangladesh has enormous potential of renewable energy. Table 2 shows the renewable energy potential in Bangladesh. Solar energy, wind, hydropower and biomass are the major sources of renewable energy. Bangladesh receives an average daily solar radiation of 4–6.5 kWh/m^2. Solar Home Systems (SHSs) have become popular projects for supplying electricity to households and small businesses in countryside. Over 0.3 million SHSs with capacity of about 15 MW are available throughout the country. The Infrastructure Development Company Limited (IDCOL), Local Government Engineering Department (LGED), Rural Electrification Board (REB), Bangladesh Power Development Board (BPDB) and different non-government organizations are engaged in solar energy programs [2].

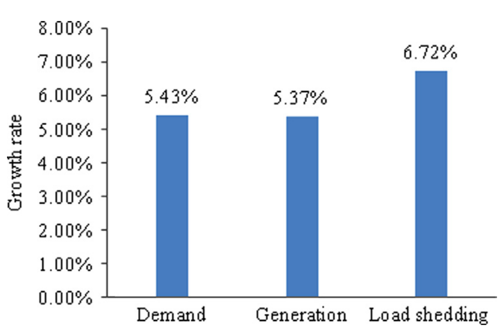

Fig. 1. Growth rate of demand, generation and load shedding [6].

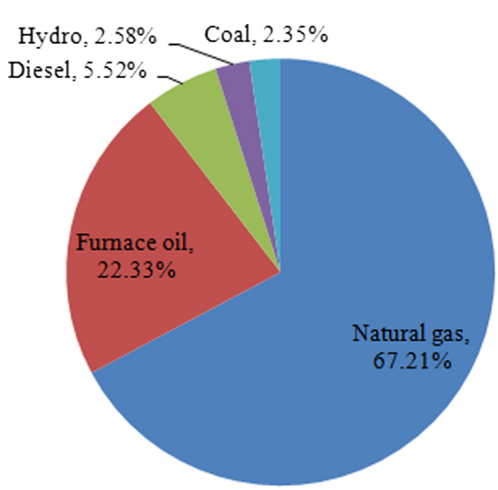

Fig. 2. Installed capacity in 2012 according to fuel type [3].

Table 2
Renewable energy potential in Bangladesh [12].

Source	Potential
Solar	Enormous
Wind	Resource mapping required
Hydro	Limited potential for micro or mini hydro (max. 5 MW). Est. hydro potential: approx. 500 MW
Domestic biogas system	8.6 million cubic meter of biogas
Rice husk based biogas gasification power plant	300 MW considering 2 kg of husk consumption per kWh
Cattle waste based biogas power plant	350 MW considering 0.752 m^3 of biogas consumption per kWh

Table 3
Present achievement and target of power generation from renewable energy [17].

Category	Achievement (MW)	Target by 2015 (MW)
Solar	50	200
Wind energy	2	200
Biomass	<1	45
Biogas	<1	45
Other RE	<1	15
Total	55	500

However, utilization, research activities and development of other renewable resources for electricity generation are still at the primary level. Biomass is one of the promising renewable energy sources for Bangladesh. Nowadays, biogas based power plants are being installed. The potentiality of wind energy based power plant depends on the availability of coastal areas and offshore islands. Presently, there are two wind turbines at Feni and Kutubdia with capacity of 2 MW each [2]. Some of the development organizations are making contributions to the exploration of the wind energy potential areas in the country. The land of Bangladesh is generally plain. Therefore, the potential of hydropower is very limited except the Chittagong hilly regions. Other potential renewable energy sources having strong possibility but not yet explored include wave, tidal energy, bio-fuels, gasohol and geothermal.

In Bangladesh, the power organizations run by government are generally involved in grid connected power plant development projects. On the other hand, mainly private sectors are engaged with off-grid home based renewable energy projects. The capacity of renewable energy based power generation in the country is about 55 MW as shown in Table 3.

The availability of electricity supply has a great assenting effect on GDP (Gross Domestic Product). GDP is one of the key indicators to measure the average living standard of individual and economy of a country. The economic development of Bangladesh depends on the progress of agriculture, industrial, commercial and other economic sectors. The development of these sectors directly and indirectly depends upon the adequate supply of electricity. Power crisis makes the pace of GDP growth rate slow. The current GDP growth of 6.10% might be the result of comparatively higher growth rate of electricity generation (8.96%). The average GDP between 2007 and 2012 was 6.21%. Whereas, the average generation of electricity was 5034 MW. The growth rate of electricity and percentage of contribution of electricity to GDP in the last 7 years are presented in Table 4.

2.2. Geographical supports for biomass production

The amount of biomass production mainly depends on the climate, temperature, soil condition and the area of available

Table 4
Contribution of electricity in GDP and its growth rate [16].

Option	2002–03	2003–04	2004–05	2005–06	2006–07	2007–08	2008–09
Contribution of electricity in GDP (%)	1.30	1.34	1.37	1.38	1.30	1.31	1.29
Growth rate of electricity (%)	7.29	9.19	8.58	7.45	1.08	6.68	3.64

Table 5
Area distribution of different land use category [19].

Land use category	Area (mha)	Percentage
Agriculture	9.57	64.9
Classified forest	1.52	10.3
Unclassified classified	0.73	5
Homestead forest	0.27	1.8
Tea/rubber gardens	0.07	0.5
Urban	1.16	7.9
Water	0.94	6.4
Other	0.49	3.2
Total	14.75	100

Table 6
Estimates of agricultural crop production in Bangladesh in 2009–10 to 2010–11 [25].

Crop	2009–10		2010–11	
	Area (acres)	Production (kton)	Area (acres)	Production (kton)
Rice				
Aus	2,431,692	1709.127	2,750,015	2132.821
Aman	1,39,92,863	12,207.162	13,95,09,33	12,791.500
Boro	1,16,31,160	18,058.962	11,787.978	18,616.780
Total Rice	2,80,55,715	31,975.251	2,84,88,926	33,541.101
Sugarcane	290,354	4490.812	287,080	4671.348
Vegetables (Summer)	626,917	1445.162	645,552	1468.159
Vegetables (Winter)	471,451	1555.271	470,414	1593.681
Total vegetables	1,098,368	3000.433	1,115,966	3061.840
Wheat	929,766	901.490	923,470	972.085
Jute	1,028,832	5089.728	1,751,325	8385.840
Pulses	593,384	220.786	627,129	232.127
Coconut	6071	402.391	7283	325.949
Groundnut	82,997	53.467	78,470	53.664
Maize	375,628	887.391	409,070	1018.282
Cotton	23,651	15.343	24,147	14.453

surplus land [18]. Bangladesh is situated between 20°34′ and 26°38′ North latitude and 88°01′ and 92°42′ East longitude. Agricultural land, forestland and urban area are the major land use types in Bangladesh. Agriculture through forestry plays an important role for mitigating the fuel needs of rural people. In 2003, biomass residues such as firewood, crop and tree contributed almost 80% to the energy consumption in the rural areas. At present, 9.57 million hectares (mha) of agricultural land, 2.52 mha of forest and 1.16 mha of urban area are available in the country. Tea, rubber gardens, water and other land use account for the remaining 2.66 mha [19]. Table 5 shows that about 65% of the land area is utilized for agricultural purposes. Very few countries in the world have such high percentage of cultivation land.

Agricultural production of a country depends on different climatic factors such as temperature, solar radiation, rainfall and atmospheric carbon dioxide, etc. Soil fertility is one of the important determinants for crop production. In Bangladesh, the tropical monsoon climate is characterized by heavy summer rainfall, high summer temperature and often-excessive humidity. Summer, rainy, winter and autumn are the four significant meteorological seasons. The range of ambient temperature is 36–40 °C in the summer season and the temperature varies from 8 to 15 °C in the winter season. The average temperature varies from 21.2 to 30.4 °C with a relative humidity of 78%. The average annual rainfall varies from 1200 mm in the extreme west to 5800 mm in the east and northeast regions [20]. Therefore, the country has really suitable climate for biomass plants production throughout the year. This has been possible for the existence of the fertile soil on the few vast floodplains that are annually replenished by sedimentation during the flood.

3. Biomass availability in Bangladesh

The common biomass resources available in Bangladesh are agricultural crop residues, wood residues, animal waste and municipal solid waste, etc. The resources can be utilized on a larger scale for electricity generation.

3.1. Agricultural crop residues

Rice, maize, wheat, coconut, groundnut, bean, vegetables, jute and sugarcane etc. are the main agricultural crops in Bangladesh. Agricultural crops produce residues that can be used to generate energy. Crop residues are collected either at the same time or after harvesting of the primary crops. Depending on the period of residues collection, there are two types of crop residues. One is field residue and other is processing residue. Field residues are generally used as fertiliser and collected from the field after harvesting. Process residues are collected from the mills, where the crops are further processed. Rice straw, rice husk, bagasse from sugarcane and jute stick cover about 46% of the total biomass energy [21]. Crop residues are used not only for renewable energy source, but also for cooking and raw manufacturing material. In Bangladesh, there is no commercial supply of gas in the rural areas. Therefore, village people use agricultural crop residues (straw, husk, etc.) as the major source of cooking fuel followed by dry cow dung, leaves and twigs, woods and kitchen by product, etc. [22]. The generation ratios for crop residues have been employed for accounting total generation of the corresponding residues. In the current study, the percentage of residues generation and recovery ratios for agricultural crops are followed from the studies of some neighboring South Asian developing countries. The residues recovery rate has been assumed as 35% for field crop residues and 100% recovery in case of process crop residues [23].

Rice is the main agricultural crop in Bangladesh that covers 76% of the total agricultural area and supplies 70% of the total calorie requirement for the nation [24]. Table 6 presents the status of agricultural crops production from FY 2009–10 to FY 2010–11. According to BBS, the volume of rice production in FY 2010–11 was 33,541.101 kilo tons (kton) of which Aus accounted for 2132.821 kton, Aman 12,791.500 kton and Boro 18,616.780 kton. Total rice production in FY 2009–10 was 31,975.251 kton, of which Aus, Aman and Boro accounted for 1709.127, 12,207.162 and 18,058.962 kton respectively. By this period, the land area for rice cultivation has increased from 28,05,715 acres to 2,84,88,926 acres. Rice straw, rice husk and rice bran are the main residues produced from rice. Rice straw is the dry stalks of cereal plants which are collected as field residues. On the other hand, rice husk is the outer surface of the rice grain and rice straw and is categorized as process residues. In Bangladesh, generally, rice straw and rice bran are used as food for cattle, poultry and fish etc. Nowadays, rice husk is being used for electricity production in a small scale.

The production of rice husk is increasing in Bangladesh. The rice milling sector is the main consumer of rice husk energy. About 70% of rice husk energy is consumed by the rice parboiling system [24]. The total amount of recoverable rice residues in Bangladesh in FY 2010–11 was 58,504.07 kton of which 51.54% and 48.46% were field and process residues respectively (Table 7).

Sugarcane is one of the potential biomass resources in Bangladesh. The volume of sugarcane cultivation in FY 2010–11 and FY 2009–10 were 4671.348 and 4490.812 kton, respectively. The land area for sugarcane cultivation has decreased from 290,354 acres to 287,080 acres. Granulated sugar, water, bagasse, molasses and dry leaves are found from sugarcane plants. Bagasse and sugarcane tops and leaves are utilized as principal resources of biomass energy. The total amount of recoverable sugarcane residues in FY 2010–11 was 2701 kton, of which 26.58% and 73.42% were field residues and process residues respectively.

Vegetables are cultivated throughout the year in Bangladesh. Depending on the season, vegetables are categorized as summer and winter vegetables. The volume of vegetable cultivation in FY 2010–11 was 3061.840 kton, of which summer accounted for 47.50% and winter 52.50%. Total vegetables production for FY 2009–10 was 3000.433 kton, of which summer and winter accounted for 48.16% and 51.84% respectively. The cultivation area has increased from 1,098,368 acres to 1,115,966 acres. In FY 2010–11, the total amount of vegetable residues was generated 1224.73 kton, of which 428.65 kton was recovered.

Wheat straws are generally used as biomass energy source. The total cultivation of wheat has increased from 901.490 kton (FY 2009–10) to 972.085 kton (FY 2010–11). But the farming area has decreased from 929,766 acres to 923,470 acres. The total amount of recoverable residues increased from 552.16 kton to 595.40 kton.

Jute is called the golden fiber in Bangladesh. Usually, jute stalks are biomass energy source. The total plantation of jute has increased from 5,089,728 kton (FY 2009–10) to 8,395,840 kton (FY 2010–11), which was 64.96% higher than the previous year. The farming area has increased from 1,028,832 acres to 1,751,325 acres. The total amount of recoverable residues increased from 534,451.44 kton to 8,815,632 kton, which is 37.12% higher than the production in FY 2009–10.

There are various types of pulses are cultivated in Bangladesh, which are locally known as Gram, Arhar, Masur, Motor, Mung, Mashkalai, Kheshari and Karikalai. The total cultivation in FY 2010–11 and FY 2009–10 were 232.127 and 220.786 kton respectively. The land area for cultivation has also expanded from 593,384 to 627,129 acres. The total amount of recoverable residues increased from 146.82 kton to 154.36 kton.

Other energy sources from agricultural crops include coconut shells, coconut husks, maize stalks, cobs, maize husks, cotton stalks, groundnut straws and husks, etc. For coconut, the total plantation has declined from 402.39 kton (FY 2009–10) to 325.949 kton (FY 2010–11). But the land area for cultivation has increased from 6071 acres to 7273 acres. From FY 2009–10 to 2010–11, the total amount of recoverable maize and groundnut residues increased by 10.56% and 0.2% respectively, while the recovery of cotton and coconut residues declined by 2.88% and 10.50% respectively.

Table 7
Generation and recoverable rates of agricultural residues in Bangladesh in FY 2010–11.

Crops	Residues		Generation ration (kton/capital/day) [23]	Residue generation (kton/year)	Residue recovery (kton/year)
Rice	Field	Process			
	Straw		1.695	56,852.17	19,898.26
	–	Husks	0.321	10,766.70	10,766.70
	–	Bran	0.83	27,839.11	27,839.11
Sugarcane	Tops		0.3	1401.40	490.50
	–	Bagasse	0.29	1354.70	1354.70
Wheat	Straw	–	1.75	1701.15	595.40
Jute	Stalks	–	3	25,157.52	8805.132
Maize	Stalks		2	2036.56	712.80
	–	Cobs	0.273	278	278
	–	Husks	0.2	203.65	203.65
Groundnut	Straw	–	2.3	123.43	43.20
	–	Husks	0.477	25.60	25.60
Cotton		Stalks	2.755	39.89	39.89
Vegetables	Residues	–	0.4	1224.73	428.65
Pulses	Residues	–	1.9	441.04	441.04
Coconut	–	Shells	0.12	39.11	39.11
	–	Husks	0.41	133.64	133.64
	Subtotal	–	–	88,938	31,427.62
	–	Subtotal	–	40,680.4	40,680.04
	Total	–	–	129,618.4	72,107.66

3.2. Animal manure

Animal manure is a mixture of organic material, moisture and ash. The mature can be decomposed both in aerobic and anaerobic conditions. Under aerobic condition, carbon dioxide and stabilized organic materials are formed. On the other hand, at anaerobic condition, methane, carbon dioxide gas and stabilized organic materials are created [26,27]. Cattle, goats, buffaloes and sheep are the general sources of animal manure in the country. Animal manure is often used as fertilizer. Biomass energy production and power generation using animal manure may become an effective energy and power demand solution in remote and rural areas of Bangladesh. Thus bad odors of manure and annoyance gas emissions from the application of raw manure are also reduced. Biogas produced from manure can meet the cooking fuel demand. Additionally, gas production from slaughter house waste has a possibility to generate electricity in a small scale. The quantity of manure production from the animals depends on age, breed and feeding habits. Also, the amount of dung yield varies with the seasons. For example, the dung yields are generated more in the rainy season than that of summer, since grasses grow more during raining [28].

Table 8 presents the number of livestock and poultry in Bangladesh from FY 2006–07 to FY 2008–09. Table 9 also estimates the cattle heads per household in the rural areas of Bangladesh. From Table 8, it is mentioned that the number of livestock and poultry are increasing day by day. Therefore, the extent of manure is also being produced positively. According to the statistics, there were about 22.97 million cattle, 1.30 million buffaloes, 22.40 million goats, 2.87 million sheep, 221.3 million chickens and 41.23 million ducks in FY 2008–09. In FY 2008–09,

Table 8
Number of livestocks and poultry in Bangladesh [30].

Livestock/poultry	Number (in million)		
	2006–07	2007–08	2008–09
Cattle	22.87	22.90	22.97
Buffalo	1.21	1.26	1.30
Goat	20.75	21.56	22.40
Sheep	2.68	2.78	2.87
Total Livestock	47.51	48.50	49.55
Chicken	206.89	212.47	221.3
Duck	39.08	39.84	41.23
Total Poultry	245.97	252.31	262.62

total population of livestock and poultry were 49.55 and 262.62 million respectively.

Table 10 shows the generation and recoverable rates of animal and poultry waste in Bangladesh in FY 2008–09. The amount of waste produced per day by livestock and poultry is estimated using the generation ratio of neighboring Asian countries. It was taken as 2.86 kg dry matter/animal/day for cattle, 2.52 kg dry matter/animal/day for buffalo, 0.55 kg dry matter/animal/day for goat, 0.33 kg dry matter/animal/day for sheep and 0.02 kg dry matter/poultry/day. The total waste produced in a year is calculated by multiplication of the waste production per year and the number of livestock/poultry. Therefore, in FY 2008–09, about 49.55 million livestock and 262.62 million poultry produced 30,016.61 kton and 1917.12 kton waste, respectively. The residues recovery rate for animal waste and poultry droppings have been assumed as 60% and 50% respectively [29]. Using these ratios, it is approximated that the amount of recoverable animal wastes and poultry droppings in Bangladesh were 18,009.96 kton and 958.56 kton respectively in FY 2008–09.

Table 9
Cattle heads per household in the rural areas of Bangladesh [31].

Farm size (Acre)	Cattle/household (avg. no.)	Household (%)
0–0.99	0.40	59
1–2.49	2.24	21
2.50–7.49	4.40	16
7.50 to above	6.80	4

Table 10
Generation and recoverable rates of animal waste in Bangladesh in FY 2008–09.

Residues	Generation ratio (kg dry matter/ capital/day)[23]	Waste generation (kton/year)	Waste recovery (kton/year)
Animal waste			
Cattle	2.86	23,978.38	14,387.03
Buffalo	2.52	1195.74	717.44
Goat	0.55	4496.8	2698.08
Sheep	0.33	345.69	207.41
Subtotal		30,016.61	18,009.96
Poultry droppings	0.02	1917.12	958.56
Total		31,933.73	18,968.52

Table 11
Organic solid wastes generating industries and their products [21].

Manufacturing industries	Major products
Food	Fast food, vegetable oil, sugar, tea and dairy, etc.
Tobacco	Cigarettes and biddies, etc.
Textile	Cotton yarn, synthetic yarn, cloth, jute mat and carpet, etc.
Paper and publishing	Paper, newsprint, books and newspaper etc.
Wood products	Hard board, particle board and cork products, etc.
Leather products	Footwear, bags, luggage etc.
Furniture (wooden)	Varity of wooden furnitures
Rubber	Cycle tire, tube, rubber footwear
Plastic	PVC pipe, office and households equipments, etc.

3.3. *Municipal solid waste*

Municipal solid waste (MSW) is the heterogeneous composition of wastes that is organic and inorganic, rapidly and slowly biodegradable, fresh, hazardous and non-hazardous, generated from various sources in urban areas due to human activities [32]. Overall, per capita waste generation depends on the economic status, food habit, age, gender of household members and seasons. The increase of solid waste in every Asian city is mainly attributed to population increase, industrialization and the improvement of living standards. The governments have realized that Green Productivity (GP) measures such as reduction, recycling, reuse, and recovery are essential elements in solid-waste management as a form of checking the rapid growth rate of waste in the cities. National awareness campaigns on GP measures are held regularly to promote recycling activities. Bangladesh, like most of the developing countries, is facing a serious environmental problem due to huge amount of MSW generation and its mismanagement [33]. The main sources of municipal solid waste (MSW) in Bangladesh are households, commercial areas, industries and hospitals.

The components of MSW are paper, plastics, leather, rubber, textiles, wood and other combustible materials. A list of organic solid wastes generated in industries and their products are displayed in Table 11. Waste heat recovery incinerator technology is used to convert the MSW into energy, which uses unprocessed MSW as fuel [34].

According to the statistics—2005, the generation of MSW in six city corporations of Bangladesh namely Dhaka, Chittagong, Khulna, Rajshahi, Barisal and Sylhet are shown in Table 12. MSW was generated at the lowest rate of 0.325 to the highest rate of 0.485 kg/capital/day and the weighted average was 0.387 kg/capital/day. A total of 7.690 kton waste generated daily in the six city corporations. The Dhaka contributed the highest quantity of 5.340 kton, which is about 69% of the total waste stream. Dhaka and Chittagong together added approximately 87% of the MSW daily. The overall socio-economic condition of the country including high growth rate of population, urbanization and industrialization are responsible for the very high percentage of MSW. Table 13 presents the involvement of various sources in total generation of MSW, where nearly 75–85% of generated waste came from the residential sector, 11–22% from the commercial sector, 1–1.5% from the institutional sector, 0.5–1.25% from municipal services and rest from other sectors.

Table 13
Sources of percentage of MSW generation in six city corporations of Bangladesh in 2005 [35].

Sources	MSW generation (%)					
	Dhaka	Chittagong	Khulna	Rajshahi	Barisal	Sylhet
Residential	75.86	83.83	85.87	77.18	79.55	78.04
Commertial	22.07	13.92	11.60	18.59	15.52	18.48
Institutional	1.17	1.14	1.02	1.22	1.46	1.29
Municipal services	0.53	0.51	0.55	1.24	1.15	0.80
Others	0.37	0.60	0.96	1.77	2.32	1.40

Table 12
Generation of MSW in six city corporations of Bangladesh in 2005 [35].

MSW generation	Dhaka	Chittagong	Khulna	Rajshahi	Barisal	Sylhet
Population (million)	11	3.65	1.5	0.45	0.40	0.50
MSW generation (kton/day)	5.340	1.315	0.520	0.170	0.130	0.215
MSW generation rate(kg/capita/day)	0.485	0.360	0.346	0.378	0.325	0.430

Table 14 shows the composition of MSW of six city corporations in Bangladesh. It was estimated that nearly 68–81% of generated waste is produced from the organic matters, 7–11% from paper, 3–4% from plastic and 9–16% from textile, wood, leather, rubber, metal, glass and others. Glass, leather and rubber were the smallest composition, while foods and vegetables were the highest portion for all cities. The biodegradable fraction (organic matter) is normally higher than any other waste source due to the use of fresh vegetables and foods and lack of food processing industries.

According to the statistics of United Nations (UN), the total population of Bangladesh in the year 2010 was 148.69 million [37]. Among them urban and rural population were 40.14 and 108.55 million respectively. The average rate of generation of MSW in the urban and rural areas of Bangladesh is 0.4 kg/capita/day and 0.15 kg/capita/day. Considering that average rate of MSW is 70% recoverable [36], the total annual amount of the biomass available from MSW in Bangladesh in 2010 was 8262.48 kton (Table 15).

3.4. Forest residues

Forest residues can play an effective role to produce biomass energy [38]. Nowadays, the unsustainable rate of deforestation, soil erosion, loss of biodiversity and traditional use of forest residues as fuel are leading to degradation of the living environment of the country day by day. But forest residues as a source of renewable energy provide various environmental benefits [20]. About 80% of the total energy consumption in Bangladesh comes from biomass resources [39]. About 17.08% of total area accounting 2.52 mha of land in the country has forest cover. Out of 2.52 mha, forest department deals with 1.52 mha, 0.73 mha are managed by ministry of land, which is designed as unclassified state forest and 0.27 mha is village forest occupying homestead land (Table 16).

Based on the location and nature, there are three major classes of forests under forest department of Bangladesh [40]:

(I) Tropical wet evergreen and semi-evergreen forest are situated in the Chittagong, Cox's Bazar, Sylhet and Chittagong hill tracts regions;
(II) tropical wet or dry deciduous forests which are commonly known as sal (Shorea robusta) forests in the plains and freshwater regions of the northwest side; and
(III) mangrove forests in the southwest of the Khulna, Chittagong, Cox's Bazar and Noakhali coastal areas. The Sundarbans is the world's largest mangrove forest located in Khulna, Bangladesh.

Table 14
MSW composition of selected locations in Bangladesh [36].

Waste category	MSW composition (wet wt%)					
	Dhaka	Chittagong	Khulna	Rajshahi	Barisal	Sylhet
Foods and vegetables	68.3	73.6	78.9	71.1	81.1	73.8
Paper	10.7	9.9	9.5	7.2	7.2	8.4
Plastic	4.3	2.8	3.1	4.0	3.5	3.4
Textile & wood	2.2	2.1	1.3	1.9	1.9	2.1
Leather & rubber	1.4	1.0	0.5	1.1	0.1	0.6
Metal	2.0	2.2	1.1	1.1	1.2	1.1
Glass	0.7	1.0	0.5	1.1	0.5	0.7
Others	10.4	7.4	5.1	10.8	4.5	9.9

Table 15
Generation and recoverable rates of MSW in Bangladesh in 2010.

Residue	Generation ratio (kg/capita/day)	Residue generation (kton/year)	Waste recovery rate (kton/year)
MSW			
Urban	0.4	5860.44	4102.31
Rural	0.15	5943.11	4160.17
Total		11,803.55	8262.48

Table 16
Total forest land of Bangladesh [19].

Category of forest	Area (mha)	Percentage
Under Forest department		
Tidal mangrove forests and plantation	0.73	4.95
Tropical moist evergreen and semi-evergreen forest	0.67	4.54
Moist or dry deciduous forests	0.12	0.81
Subtotal	1.52	10.3
Unclassified state forest	0.73	4.95
Village forest	0.27	1.83
Total	2.52	17.08

Table 17
Estimated wood and bamboo production in Bangladesh till 2020 [42].

Year	Wood, (million m^3)	Village, (million m^3)	Total wood, (million m^3)	Bamboo (million culms)
1990	0.87	4.01	4.88	70.51
2000	0.18	6.07	6.25	78.61
2010	1.10	7.86	8.96	63.45
2020	3.62	10.62	14.24	65.68

In the rural areas, for lack of sufficient cooking fuel, fuel wood is generally collected from the nearest village forest. It is estimated that the rate of reduction of forest land in Bangladesh is about 3.3% per year, because of illegitimate deforestation for collecting firewood and making furniture. This rate of forest diminution is strictly unsustainable [41]. Both tree and wood residues are extracted from forest. Twigs, leaves, bark and roots are the main tree residues. Efficient use of forest residues can be a potential source of energy in Bangladesh.

Table 17 shows the estimated wood and bamboo production in Bangladesh until 2020. The results present that the wood production rate in the forest is lower than the homestead forests. It shows that the rural people are more conscious about their fuel wood necessity.

According to the statistics, the total fuel wood production was 6.932 million tons in Bangladesh in 2003 [29]. The recoverable rate of forest residues is about 80%, while the rest 20% of a tree is mainly used as timber for making furniture and fittings. Saw logs, veneer logs, plywood, pulpwood, particle board and fuel wood are the common sources of wood residues. Saw logs and veneer logs are the potential sources of bark, sawdust, trimmings, slabs and edgings, planer shavings, split wood and veneer waste residues. Plywood and other industrial round wood logs are produced in the form of rejected plywood, veneer clippings and waste, panel trim and sander dust. On the other hand, residues from pulpwood and particle board are generated in the form of screening fines, panel trim, sawdust and sander dust [43]. Table 18 presents the annual generation rate of forest residues in 2004, when 1.816 million tons of tree residues and 0.123 million tons of sawdust were produced for energy purposes. As in terms of forest residues, 100% recovery rate is generally considered. Using this recovery rate, the total amount of recoverable residues from forests and forestry industry in Bangladesh was 8.871 million tons in 2004 [29].

4. Energy potential from biomass residues

From the Tables 9, 12, 17 and 22, it is estimated that the total annual generation and recoverable amount of biomass in Bangladesh is about 182.22 and 108.208 million tons/year respectively.

Table 18
Generation of forest residues in 2004 [29].

Types of residues	Generation (million tons)
Fuel wood	6.932
Tree residues	1.816
Sawdust	0.123
Total	8.871

Agricultural residues supply 66.64% of the total recoverable biomass, which is followed by 17.53% from animal wastes and poultry droppings, 7.64% from municipal solid waste and 8.19% from forest residues. The lower calorific value, known as heat of combustion, has been employed to estimate the recoverable energy potential from the residues. According to the estimation, the total amount of biomass energy available is 1434.14 petajoule (PJ), which is equivalent to 398.37 terawatt-hours (TWh). The energy contents of agricultural residues, animal wastes and poultry droppings, municipal solid waste and forest residues are 68.29%, 18.30%, 5.8% and 7.5% of total energy potential, respectively. From the agricultural residues, rice residues produce the maximum amount of energy 790.79 PJ, which is equivalent to 219.66 TWh (Table 19).

Table 19
Calorific values, moisture content and energy potential of biomass residues.

Residue	Moisture content (%)	Calorific values (GJ/ton)	Energy content (PJ)
Field residues			
Rice straw	12.7	16.30	283.15
Sugarcane tops	50	15.81	3.56
Wheat straw	7.5	15.76	8.679
Jute stalks	9.5	16.91	134.75
Maize stalks	12	14.70	9.22
Groundnut straw	12.1	17.58	0.667
Cotton stalks	12	16.40	0.575
Residue from vegetables	20	13.00	4.457
Residue from pulses	20	12.80	4.516
Subtotal			449.674
Process crop residues			
Rice husk	12.4	16.30	153.73
Rice bran	9	13.97	353.91
Sugarcane bagasse	49	18.10	12.505
Coconut shells	8	18.53	0.667
Coconut husks	11	18.53	2.204
Maize cob	15	14.00	3.308
Maize husks	11.1	17.27	3.126
Groundnut husks	8.2	15.66	0.368
Subtotal			529.818
Total agricultural crop residues			979.492
Other biomass			
Animal waste		13.86	249.618
Poultry droppings		13.50	12.94
MSW	45	18.56	84.34
Fuel wood	20	15.00	83.18
Tree residues		12.52	22.8
Sawdust	20	18.00	1.77
Total			1434.14

5. Technologies for biomass conversion to energy

5.1. Thermo-chemical conversion

Thermo chemical processes are commonly employed for converting biomass into higher heating value fuels [44]. The main thermo-chemical conversions of biomass are direct combustion, gasification and pyrolysis [45,46].

5.1.1. Direct combustion

In the direct combustion, biomass is utilized as a fuel to generate hot flue gases, which are used to produce steam with sufficient air in the combustion chamber. Heat and electricity can be simultaneously generated (cogeneration) using turbines. Generally, biomass combustion technologies can be categorized into the fixed bed and fluidised bed combustion systems [47,48]. Combustion of biomass produces hot gases at temperatures of around 800–1000 °C [49].

5.1.2. Gasification

Gasification is the conversion of biomass into a combustible gas mixture by the partial oxidation of biomass at high temperatures. Typically, the range of temperature is about 800–900 °C. The produced gas of low calorific value (about 4–6 MJ/N m^3) can be burnt directly or used as a fuel for gas engines and gas turbines [49–51].

5.1.3. Pyrolysis

Pyrolysis is a decomposition process of biomass at suitable operating temperature in the absence of oxygen [47]. Conventional slow, fast and flash are the three processes of pyrolysis. Slow pyrolysis is used for the production of charcoal under slow heating rate of 0.01–1 Kelvin per second (K/S) and temperature of 273.85–626.85 °C. Fast pyrolysis is associated with the rapidly heated biomass at high temperature (576.85–976.85 °C) and heating rate (10–200 K/S). The operating temperature and heating rate for flash pyrolysis are about 776.85–1026.85 °C and above 1000 K/S respectively. The flash pyrolysis is generally used to convert small biomass particles into liquid fuel (bio-oil or bio-crude) [27].

5.2. Bio-chemical conversion

5.2.1. Anaerobic digestion

Anaerobic digestion is the conversion of organic material directly to gas, called biogas [46]. Biogas is mainly composed of methane (CH_4) (about 50–70%) and carbon dioxide (CO_2) (about 30–40%). It also contains small amounts of several organic gases like hydrogen sulfide (H_2S), nitrogen (N_2), hydrogen (H_2), ammonia (NH_3) and carbon monoxide (CO) [27,52].

5.2.2. Fermentation

Fermentation is used commercially on a large scale in various countries to produce ethanol from sugar crops (e.g. sugar cane, sugar beet) and starch crops (e.g. maize, wheat). The biomass is ground down and the starch is converted to sugar by enzymes. After that, sugar is converted to ethanol using yeast and ethanol is purified by distillation. The solid residue from the fermentation process can be used as cattle feed. In the case of sugar cane, the bagasse can be used as fuel for boilers or subsequent gasification [46].

Comparative demonstrations of the energy efficiency of biomass energy conversion technologies for electricity generation and electricity cost from biomass based power generation are given in Tables 20 and 21 respectively.

6. Biomass related technology practices in Bangladesh

6.1. Biogas plant

Natural gas plays an important role in the industrialization and urbanization of the country. It is estimated that the demand for natural gas will be about 13.6 trillion cubic feet (tcf) in 2020, about

Table 20
Energy efficiency of biomass to energy conversion technologies [53].

Power generation method	Fuel type	Efficiency
Direct combustion		0.19–0.26
Thermal gasification combined cycle		0.16–0.30
Supercritical water gasification combined cycle	Biomass	0.29
Methanol-fired		0.26
Anaerobic digestion of biomass		0.40
Gasified cogeneration system	Vegetable and animal	0.22
Fluidized bed gasification combined cycle		0.42
Fluidized bed gasification gas cycle	Wood waste	0.34
Fluidized bed gasification steam turbine		0.31
Grate firing		0.30

Table 21
Electricity cost from biomass based power generation [53].

Biomass source	Country	Technology	Capacity (MW)	Cost (US$/kWh)
Wood chip	Europe	Pyrolysis	20	0.1136
Rice husk	China	Gasification	1	0.0425
Agriculture residue	Canada	Combustion	450	0.0503
Forest residue	Canada	Combustion	137	0.0630
Wood	India	Gasification	0.54	0.30–0.55
Rice straw	Thailand	Direct combustion	5–20	0.0676–0.0899
Thinned wood	Japan	Gasification	0.3	0.2000
Forest harvest residue	Canada	Gasification	50	0.0604–0.0623

26.7 tcf in 2030 and about 62 tcf in 2050. Since 84.5% of electricity generation and all urea fertilizer manufacturing companies depend on natural gas, it appears that the present reserve of 11.6 tcf will not run beyond 2020. Therefore, biogas technology can play an effective role regarding this issue. Also, biogas plants improve health and sanitation conditions of rural people, increase food security through the expansion of agriculture and livestock business, diminish deforestation and CO_2 emissions. The low cost raw materials for biogas are widely available everywhere in Bangladesh [54]. Biogas is a kind of gas found mainly from anaerobic fermentation of animal and municipal wastes. It is one of the promising renewable energy resources, which is largely used for cooking, rural and semi-urban electrification in Bangladesh. The electricity generated from biogas can be used for lighting, running electrical domestic devices like TV, refrigerator etc. Moreover, bio-slurry, a by-product of biogas plant is used as organic fertilizer and fish feed. Three types of biogas plants are available namely floating dome type, fixed dome type and bag type. In the floating dome type, dome is used as gas container and maintains gas pressure. A circular type brick made tank is used as gas container in fixed dome type and the gas pressure is maintained by a hydraulic chamber. Bag type is made of polythene and worked as gas container [55,56]. But nowadays, the fixed dome type plants have become popular in Bangladesh. Tables 22 and 23 show the feed requirement of biogas plants with different capacities and efficiencies of typical household stoves in South Asia respectively.

In 1972, first biogas plant was set up in the university campus by Bangladesh Agricultural University (BAU). The biogas plant was developed to study the gas production characteristics. In 1992, the Institute for Fuel Research and Development (IFRD), a research institute of Bangladesh Council of Scientific and Industrial Research (BCSIR) and Dhaka City Corporation built a biogas plant of 85 m^3 for treatment of city garbage [58]. Tables 24 and 26 show the list of biogas plants installed by different organizations. Up to April 2012, Infrastructure Development Company Limited (IDCOL) along with its partner organizations has installed 22,549 family sized fixed dome

Table 22
Capacity, feed requirement and cost of biogas plants [57].

Capacity (m^3)	Feed requirement (kg/day)		Operation (hours/day)	Cost (in US$)
	Cattle manure	Poultry droppings		
2.0	54	8	4–5	413
2.4	65	35	5–6	456
3.2	87	45	6–8	500
4.8	130	70	10–12	625

Table 23
Efficiencies of typical household stoves in South Asia [23].

Fuel	Combustion efficiency (%)	Overall efficiency (%)
Biogas	99	57
Liquefied Petroleum Gas (LPG)	98	54
Kerosene	98	50
Fuel wood	90	23
Agriculture residues	85	14
Dung	85	11

type biogas plants in different regions of Bangladesh. The plants are designed for two types of raw materials-one is for cattle dung and human excreta and another for poultry droppings. There are six different capacities of plants for each design. The gas production capacities of the plants are 1.2, 1.6, 2.0, 2.4, 3.2 and 4.8 m^3. Biogas plants with 3.2 and 4.8 m^3 are used for multiple households.

6.2. *Improved cooking stoves*

Bangladesh is one of the vulnerable countries of global climate change. In the rural areas, food is normally cooked in the traditional cooking stoves and huge amount of CO_2 is produced from these stoves. Population of the country is increasing at an unsustainable rate. It leads to the increased need of fuel wood [59]. A rise in the efficiency of biomass fuel utilization is one of the effective solutions of demand for cooking fuel [60,61]. Research undertaken in the IFRD has shown that the efficiency of biomass fuel in traditional mud cooking stoves used in Bangladesh is very low and it varies from 5% to 15% [62]. Using the efficient cooking stoves, furnaces and boilers, a large quantity of biomass resources will be saved [63]. The features of improved stoves can be mentioned as (i) a chimney to remove kitchen smoke immediately (ii) stove should be enclosed as if the heat can be maintained for longer period (iii) suitable design of pot holder to improve heat transfer from fire to the base of pot (iv) air dampers to maintain

Table 24
Summary of biogas plants installation by organizations excluding IDCOL.

Organization	Installation period	No of biogas plants installed
Bangladesh Council of Scientific & Industrial Research (BCSIR)	1973–2005	22,100
Local Government Engineering Department (LGED)	1985–2001	7000
Department of Environment (DoE)	1979–1983	260
Bangladesh Rural Advancement Committee (BRAC)	1987–2005	300
Department of Livestock Services (DLS)	1988–1994	70
Bangladesh Small & Cottage Industries Corporation (BSCIC)	1983–1988	30
Bangladesh Agricultural Development Corporation (BADC)	1983–1984	20
Danish International Development Agency (DIDA)	1982	4
Bangladesh Agricultural University (BAU)	1971–1973	2
Housing & Building Research institute (HBRI)	1981	2
Bangladesh Academy for Rural Development (BARD)	1974	1
Bangladesh Commission for Christian Development (BCCD)	1978	1
Bangladesh Rice Research Institute (BRRI)	1983	1
Total		29,791

Table 25
Cogeneration in sugar mills using sugarcane bagasse as fuel [71].

No	Name of sugar mills	Annual operation (days)	Installed capacity (t/day crushed)	Cane crushed (tons)	Capacity (MW)	Electricity generation (MWh)
1	Panchagar	150	1016	143,952	2.0	2967
2	Thakurgan	148	1524	200,213	3.0	3878
3	Setabganj	114	1250	135,872	4.0	3838
4	Shyampur	138	1016	125,111	2.0	2897
5	Rangpur	131	1321	154,421	2.6	3879
6	Jaypurhat	136	2032	220,294	2.5	3586
7	Rajshahi	162	2000	234,072	3.5	5519
8	Natore	167	1500	263,941	4.0	5972
9	North Bengal	166	1500	270,979	2.0	4159
10	Kushtia	130	1524	162,325	3.0	3104
11	Carew	175	1150	185,752	3.0	3446
12	Mobarakganj	156	1500	218,985	2.0	1888
13	Faridpur	160	1016	171,431	2.0	299
14	Zeal Bangla	155	1016	143,091	2.0	3138
	Total		19,365	2,630,439	37.6	48,570

the flow of air (v) ceramic filter to reduce the heat loss (vi) a mouth to remove ash and (vii) suitable metal sheath, while using multiple pots concurrently as if pots can be heated properly. The improved stoves can be categorized into three types namely stoves without chimney, stoves with chimney and stoves with waste heat recovery system. The fuel consumption rate of stoves without chimney and stoves with chimney are 50–55% and 60–65% less than traditional stoves respectively. Under projects funded by the government, IFRD is engaged in a pilot-scale distribution of improved cooking stoves, which can save around 50–70% of fuel compared with traditional stoves [64]. Efforts have been made by BCSIR for the spreading of improved stoves. The total number of improved stoves setup so far is around 0.3 million [62].

6.3. Biomass gasification

Biomass gasification is the process for converting solid biomass fuels into a combustible gas mixture of CO, H_2, traces of CH_4 and other hydrocarbon [65]. The solid biomass fuels include agricultural and forest residues. The gas mixture is usually called producer gas. This technique is still at infancy stage in Bangladesh. In Bangladesh, Dreams Power Private Limited first initiated small scale rice husk gasifier based power plant in October 2007. The plant is located at Gaspur village in Kapasia of Gazipur district. The total capacity of the power plant is 250 kW. It has two units having equal capacity to supply 125 kW. The total investment for developing the complete infrastructure including the installation of power generation, gasifier, dual-fuel engine, generator and distribution cost etc. was about BDT 25 million. IDCOL supplied loans and grants of about 20% and WB provided 60% of the total cost as grant, while the company supported 20% of the total investment [66]. From 'Rice Mills Owners Association' in Bangladesh, it is found that a total of 540 rice mills are in operation in the country. The number of lower-midsized rice mills with capacity range greater than 25 to 50 t/day are reported to be about 490 and that of mid to large sized mills having capacity from 30 to 120 t/day are about 50 units. If the average capacity of the mills is estimated at 30 t/day, then the total technical potential of electrical power generation will be 171 MW [67,68].

6.4. Biomass briquetting

A briquette is a hunk of combustible material, which is used as fuel to initiate and continue fire. In Bangladesh, biomass briquette plays a vital role in meeting cooking fuel demand of rural people. For producing one metric ton of rice husk briquette fuel at production level, the energy generated by briquette machine was found to be only 175 kWh [24]. Biomass briquette offers several advantages over the traditional bio-fuel, including higher volumetric calorific value, easy collection, transportation, lower cost, accumulation, longer burning duration and cleanliness. It also provides environmental benefits by reducing deforestation and CO_2. Moreover, utilization of biomass briquette is an important source of income, especially for rural poor woman. Since Bangladesh is one of the major rice producing countries in the world, residues from rice, especially rice husk is used for producing briquette fuel. Wood sawdust and other agricultural residues are also used for generating briquette fuel. In order to briquette the biomass residues, two types of machines are used. One is piston press and another is heated die screw extruder type. In Bangladesh, briquette system was first introduced in Sylhet in 1990 by a rice mill owner, who imported a briquette production unit from Taiwan to tackle problems related to disposal of rice husk [69]. Briquette unit availability is mostly subjected to raw materials availability. Briquette units are mostly located near rice mills and generally, districts with high availability of rice husk have higher number of machines. In 1999, Khulna University of Engineering Technology (KUET) reported that about 906 heated die screw extruder type machines are operating in the country [70].

Moreover, sugarcane bagasse is a potential source of energy in Bangladesh, particularly in north-western region, which is starved for energy. There are about 15 sugar mills in that region that produce around 2,700,000 million tons of bagasse annually. Using bagasse, the 14 sugar-mill based cogeneration power plants have already been installed with total generation capacity of 37.6 MW [71]. A list of existing cogeneration stations in sugar mills is given in Table 25.

7. Plans and strategies to promote biomass use in Bangladesh

7.1. Biomass projects by different organizations

The Government of Bangladesh (GoB) has taken different steps to develop the renewable energy technologies. According to the Renewable Energy Policy—2009, the target is to meet the

Table 26
Summary of biogas plants installation up to April 2012 by IDCOL [73].

Organization	No of biogas plants installed
Grameen Shakti (GS)	12,795
Rahman Renewable Energy Co. Ltd. (RB)	972
Save our Urban Life—SOUL	748
Kamrul Biogas and Compost Fertilizer Research Development Co. Ltd. (KB)	783
Hossain Biogas and Compost Fertilizer Co. Ltd. (HB)	634
Rural Services Foundation (RSF)	925
Srizony Bangladesh	610
DESHA	655
Shubashati	493
Basic Organization Network for Development and Humanitarian Aid for Nation	407
Nirapad Engineering	344
Bhelabazar Shamaz Unnayan Sangstha (BSUS)	316
Development of Poor Society (DOPS)	190
Samaj Unnayan Kendra (SUK)	331
Anannyo Samaj Kallyan Sangstha (ASKS)	178
Mohila Bohumukhi Sikkha Kendra (MBSK)	103
Access toward Livelihood and Welfare Organization (ALWO)	132
Sonali Unnayan Foundation (SUF)	99
Jahanara Biogas Construction Co. Ltd. (JB)	82
SETU	93
RISDA–Bangladesh	310
Rural Reconstruction Foundation (RRF)	164
Shariatpur Development Society (SDS)	41
Barendra Advancement Integrated Committee (BAIC)	68
Gonoshasthaya Kendra (GK)	44
Gram Bikash Kendra (GBK)	61
Center for Community Development & Research (CCDR)	340
ADAMS	68
Bright Green Energy Foundation (BGEF)	22
Ghashful	33
NUSRA	20
GHEL	80
Grameen Motsho O Poshusampad Foundation	48
PIPASA	9
LPEP Renewable Energy Bangladesh Ltd.	5
WAVE Foundation	22
MAKS	5
Others	283
Total	22,549

demand for 5% of total electricity using renewable energy technologies by the year 2015, 10% by 2020 and 20% by 2035. The government and private organizations are developing several projects on biomass with the aid of domestic and international funds.

The state-owned non-banking financial institution, IDCOL is playing major role to develop biomass based projects. IDCOL is currently implementing two projects on biogas plant and one project on biomass gasification. In the field of biogas, the International Organization, Netherlands Development Organization (SNV) has initiated the National Domestic Biogas and Manure Program (NDBMP) in 2006 with the objective of developing and disseminating domestic biogas plants in rural areas. The target of the program was to install a total of 37,269 domestic sized biogas plants during the period 2006–2012. However, the program is still going on. Till April 2012, more than 22,000 biogas plants have been set up in different parts of the country (Table 26). Three types of partner organizations (POs) namely Construction Partner Organizations (CPOs), Lending and Construction partner Organizations (LCPOs) and Manufacturing Partner Organization (MPOs) are associating with IDCOL. Currently, 32 POs are engaged with NDBMP. A budget of EUR 23.61 million has been fallocated or NDBMP. The cost is being borne by individual households, SNV, Kreditanstalt für Wiederaufbau (KfW) and GoB. A financial support of BDT 9000 is provided by IDCOL to a customer, who installs plant according to the specifications and standard set by IDCOL/SNV/Kfw. IDCOL is also providing 80% of the LCPOs loan at 6% interest with 7 years loan tenure and 1 year grace period [72].

IDCOL is also implementing a project to generate electricity from poultry droppings based biogas plants. The objective of this project is to produce both electricity and organic fertilizer. A budget of BDT 149.40 million has been allotted for construction of the three 100 kW biogas based electricity generation plants, one in Mymensingh and two plants in Gazipur and one 50 kW organic fertilizer plant in Gazipur. The raw materials for biogas production will be provided from the Paragon Poultry Limited (PPL). Power generation using biogas will be distributed to the adjacent poultry farms of PPL at the cost of BDT 4.00 kWh^{-1}. The slurry produced from the biogas digesters will be fed to the planned fertilizer plant for composting purposes. The market price of the organic fertilizer will be BDT 15 kg^{-1} packet and BDT 400 per 40 kg packet [72].

To develop ICs program, under Fuel Saving Project, IFRD of BCSIR is implementing different projects for utilization of the traditional and commercial fuels more efficiently. The two Annual Development Program (ADP) projects on dissemination of ICs have been successfully implemented by IFRD of BCSIR, Ansar-VDP (Village Defense Party) and Bangladesh Rural Development Board (BRDB). Under the first phase (1994–1997) of the project, 62,848 ICs were disseminated. Under the second phase (1998–2001) of the project, a total of 117,573 ICs were disseminated all over the country. The main objectives of the projects were to save the amount of cooking fuels consumption by using the ICs and to ensure air pollution-free environment in the rural areas. The project also developed a number of experts for dissemination of ICs through basic training courses.

Apart from this, some of the dissemination works are also being continued all over the country by government and non-governmental

organizations including German Agency for International Cooperation (GIZ), Grameen Shakti (GS), Village Education Resource Center (VERC), United Nations Development Program (UNDP) & UN-Habitat and Winrock/VERC etc. A list of the dissemination programs of ICs is given in Table 27.

In the field of biomass gasification, IDCOL is currently financing a project to generate electricity using rice husk gasification process. A budget of BDT 64.25 million has been allotted to construct a 400 kW rice husk gasification based power plant and also a precipitated silica production plant at Chilarong, Thakurgaon. Precipitated silica used in rubber, toothpaste and chemical industries, is currently imported from the foreign countries. Therefore, the main objectives of this project are to generate power and to reduce import of precipitated silica. Sustainable Energy & Agro-resource Limited (SEAL) is implementing the project with the technical help of Orbit, India.. Rice husk will be used as fuel for power generation. Generated power will be distributed to a silica plant with 75 kW, one poultry hatchery with 300 kW and 30 irrigation pumps with 10 kW each and several rice mills in that region. After implementation, hopefully production of the silica will be 918 t/year [72].

Other organizations that are currently involved in various biomass technologies include Local Government and Engineering Department (LGED), Rural Electrification Board (REB), Bangladesh Power Development Board (BPDB), Sustainable and Renewable Energy Development Agency (SREDA), Bangladesh Rehabilitation Assistance Committee (BRAC), Rural Services Foundation (RSF), different NGOs and community groups. The other important donors to implement the projects are Asian Development Bank (ADB), The World Bank (WB), Japan International Cooperation Agency (JICA), Global Environment Facility (GEF), Urban Partnership for Poverty Reduction (UPPR), U.S. Agency for International Development (USAID), Practical Action (PA), Swedish International Development Agency (SIDA), UK Department for International Development (DFID), Climate and Clean Air Coalition (CCAC) and Global Alliance for Clean Cook stove (GACC) [13].

7.2. Promotion techniques

The GoB and private organizations have undertaken several activities to promote biomass technologies through various strategies [77–79]. Some of the strategies are given below:

(a) Using mass media—Television, radio and other mass media could be used to promote biomass technologies by informing the benefits, costs, subsidies and loan provisions. Moreover, posters, leaflets and pamphlets containing advantages of biomass utilization can be distributed among the people to increase awareness.

(b) Arranging training courses—The government and non-government organizations can arrange orientation training courses for the potential users, NGOs workers, and school teachers to make them aware about biomass technologies.

(c) Organizing exhibitions and demonstrations—The government and non-government organizations could organize exhibitions and demonstrations on biomass technologies. Since 1986, seminars on Renewable Energy Technologies (RETs) including biomass technologies have been regularly organized by the Ministry of Science and Information & Communication Technology at the district, upazila and village levels in the country.

In order to ensure the future energy security and establish sustainable environment, a number of programs and strategies have already been undertaken to promote the renewable energy applications. Government has adopted pro-investment strategies to encourage private sector in renewable energy sector. In order to promote RETs, all raw materials related with producing renewable energy are charged 15% less VAT. An independent organization, Sustainable Environment Development Agency (SEDA), has already been established by GoB to coordinate and facilitate activities of agencies for promoting renewable energy. The investors in renewable energy projects are exempted from corporate income tax for five years. Power division of Ministry of Power, Energy and Mineral Resources (MPEMR) and SEDA, in consultation with Bangladesh Power Regularity Commmission (BERC) have created a regulatory framework to encourage the generation of electricity using RETs. Additionally, a network of micro-credit support system has been established in rural areas to supply financial support for purchasing necessary equipments [67].

7.3. Research activities

In Bangladesh, several technical institutions and universities are engaged in research and development activities in the field of biomass energy. In biogas field, mainly BCSIR, LGED, BRAC, GS, Bangladesh Agriculture University (BAU) and Bangladesh University of Engineering & Technology (BUET) are undertaking researches on cost reduction, proper methods of utilizing slurry, increasing efficiency on biogas technology and modeling biogas plants etc. In the ICs field, IFRD of BCSIR and GS are working on designing ICs. BCSIR has already developed 31 updraft and 9 downdraft models of ICs. In Khulna University of Engineering & Technology (KUET), the research and development activities on biomass briquetting are being carried out by the financial aid from SIDA and technical support from Asian Institute of Technology (AIT) since 1997 [21]. Researches on pyrolysis for production of alternative liquid fuel from organic solid wastes have been progressing in Rajshahi University of Engineering & Technology (RUET) since 2000. Although, biomass gasification plants are being implementing in the country, research in this field is still at

Table 27
Dissemination of ICs by different organizations [74–76].

Name	Duration	Stoves disseminated	Current status/future plans
BCSIR	1994–1997 (Phase I) 1998–2001 (Phase II)	BCSIR:12,577 Ansar-VDP: 32,932 BRDB: 17,000 BCSIR: 46,597 Ansar-VDP: 31,555 BRDB: 39,4	Phase III announced to distribute 28,000 stoves using the Climate Change Trust Fund
GIZ	2004–2011	175,000	Uncertain funding situation beyond 2012.
GS	2006–present	480,000	Monthly sales of 25,000 and growing
VERC	2000–11	48,000	42, 000 stoves installed by a network of 93 NGOs coordinated by VERC with support of ARECOP; over 6000 stoves installed under carbon finance project started 2008
UNDP & UN-Habitat	2011	40,000	Implemented through POs which receive technical assistance from GIZ. Plans to expand to 400,000
Practical Action	2001–11	7000	Expansion through full time and part time entrepreneurs
Winrock/VERC	2005–07	580	Entrepreneurs continue sales beyond end of project

primary stage. Only Bangladesh Rice Research Institute (BRRI) is conducting research activities on rich hush gasification.

8. Conclusion

The principal aim of this study was to present an overview of biomass energy resources in Bangladesh. By considering the geographic position, energy situation and environmental concern, biomass can be considered as a favorable energy source compared to the other electricity generation sources. Agriculture residues, animal and poultry waste, municipal solid waste and wood residues are the major sources of biomass in the country. The theoretical assessment of sustainable biomass potential shows that annually biomass could provide over 1000 PJ energy, which can contribute towards the meeting of the present energy demand. At present, a number of projects are being implemented by the government and private organizations with the aid of local and international donors. At the same time, in order to improve this sector, the government should be more conscientious for overcoming technical and commercial barriers, monitoring and fast implementation of projects, providing funds, reducing cost, raising mass awareness and research activities.

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